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A novel approach for barriers to industrial energy efficiency

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ABSTRACT

A critical review of the literature highlighted the need for a new taxonomy encompassing the most relevant barriers stemmed from previous studies, and accounting for interactions and independences of the barriers to avoid overlaps and implicit interactions. Based on an extensive literature review the paper provides a novel approach for barriers to the adoption of industrial energy-efficient technologies, coping with the issues risen by the review of the literature. We developed a taxonomy adaptable to empirical research, and able to evaluate the differences between perceived and real barriers, the effect of the barriers on decision-making processes, and the interactions among barriers. We modeled three types of interactions, i.e., causal relationship, composite effect and hidden effect, in order to start analyzing the dynamics among barriers, and tested the taxonomy in a preliminary investigation. The study proposes a useful instrument both to enterprises and policy-makers to identify critical factors to improve industrial energy efficiency and to open the research to further investigation in this topic.

Contents

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1. Introduction

The global concern for the primary energy consumption increase, the correlated increase of the GHG-emissions and the uncertainty on the effective available resources has made energy efficiency a priority on the policy agenda of most countries. In Europe, increasing energy efficiency has been broadly considered as the best method to obtain some of the most important objectives set by the European Commission in 2008 for what concerns the reduction (20%) of GHG-emissions and 20% reduction of energy consumption [1], and a relevant contribution could come from industry, responsible of about 50% of world's delivered energy consumption [2].

However, still many industries do not pursue the adoption of energy-efficient technologies, even if economically and environmentally attractive, and often easy to be implemented, as shown by Abdelaziz et al. [3] and Saidur [4]. This misalignment has been historically called *energy-efficiency gap* [5], and has been widely investigated in the literature [5–10]. This term has been recently revised by Backlund et al. [11], introducing an *extended energy efficiency gap*, in order to point out the potential of investments in energy-efficient technologies with that coming from continuous energy management practices. This clarifies that interdisciplinary efforts – in terms of perspectives on barriers, energy audits, energy management, policies and programs – need to be performed in order to improve energy efficiency in industrial systems [12]. Nonetheless, as in many industrial activities the energy expenditures are often less than 5% of total production costs, investments to improve energy efficiency are not fully appreciated: actually, neither they are perceived as strategic [13,14] nor their characteristics are fully recognized in terms of relative advantage, technical context and information context [15]. Moreover, the full spectrum of benefits coming from the implementation of energy-efficient technologies and practices is not fully appreciated yet [16,17]. This is quite frequent both for non-energy intensive enterprises, and small and medium-sized enterprises (SMEs). Indeed, as found by a recent study commissioned by the Observatory of SMEs led by the European Commission [18], only 4% of European SMEs has in place a comprehensive system to monitor and improve energy efficiency. This happens despite energy saving technologies and practices may also represent a strategic and competitive advantage through the development of new markets or new market opportunities, as shown by various authors [19–21].

On the basis of a comprehensive review of the literature on barriers and existing taxonomies for barriers to industrial energy efficiency improvement, we propose a new taxonomy able to encompass the most relevant barriers stemmed from previous studies. Moreover, the novel approach accounts for interactions and interdependences of the barriers to avoid overlaps and implicit interactions. This enables to come to a taxonomy that can be used in empirical research and is able to evaluate the differences between perceived and real barriers, the effect of the barriers on decision-making processes, and the interactions among barriers. The taxonomy represents an useful instrument both to enterprises and policy-makers to identify critical factors to improve industrial energy efficiency. In this review we consider energy conservation and energy efficiency improvement to be analogous. A preliminary test has been carried out in some exploratory cases to validate the new taxonomy.

The paper is structured as follows: in Section 2 of this paper we critically evaluate existing literature. In Section 3 we analyze the needs for a new taxonomy, which, in Section 4, is proposed. Finally, we draw conclusions and highlight some further research issues in Section 5.

2. Literature review

The existence of a gap between the potential profitable energy efficiency improvement and the effectively implemented one is clear since early 1970s. We have performed a review of the most relevant contributions in the literature that categorized the barriers for energy efficiency. Indeed, a comprehensive categorization of the barriers in taxonomies is necessary to obtain a complete picture of a complex problem, allowing to more effectively integrate barriers into models for industrial energy demand, but also to formulate more detailed and realistic policy responses to reduce the impact of barriers, as highlighted by Fleiter et al. [22].

The first attempt to provide a systematic study of the problem has been performed by Blumstein et al. [23], that defined and classified various types of social and institutional barriers to cost-effective energy conservation measures. According to Blumstein et al., six categories of barriers can be identified, although not all barriers can be easily referred to a single category:

(i) *Misplaced incentives*: the economic benefits of energy conservation do not always accrue to the person who is trying to conserve;
(ii) *Lack of information:* the efficient working of the market depends on the parties to transactions having adequate information;
(iii) *Regulation:* if a cost-effective measure conflicts with existing codes or standards, its implementation will be difficult or impossible;
(iv) *Market structure:* even though a conservation measure or device is cost effective, it may not be on the market;
(v) *Financing:* energy conservation measures often require an initial investment; thus, the availability of capital may be necessary for some measures;
(vi) *Custom*: if a cost-effective conservation measure requires some alteration in the habits of the consumer – affecting the "this is the way we have always done it" – or seems contrary to some accepted value, it may be rejected.

Another classification can be found in the Third Assessment report by the Intergovernmental Panel for Climate Change (IPCC) [24], that performed an extensive review of the existing literature for the barriers to greenhouse gas (GHG) emissions mitigation. In this study, the IPCC has put in evidence the sector and technology-specific barriers to eight sources, as follows: (i) *Technological Innovation*, (ii) *Prices*, (iii) *Financing*, (iv) *Trade and Environment*, (v) *Market Structure and Functioning*, (vi) *Institutional Frameworks*, (vii) *Information Provision*, and (viii) *Social, Cultural, and Behavioral Norms and Aspirations.*

Painuly and Reddy [25] addressed barriers to electricity conservation measures, both on the supply side as well as the demand side. The authors have divided the barriers into: (i) *Technical*, (ii) *Institutional*, (iii) *Financial*, (iv) *Managerial*, (v) *Costs*, and (vi) *Information*.

de Almeida et al. [26] provided an important contribution on barriers, in particular considering the practical issues that should be addressed by policy-makers. The study provides an insight on energy-efficient motor technologies, with a categorization of five elements: (i) *Awareness of the options*, (ii) *Technical options*, (iii) *Economic barriers*; (iv) *Internal conflicts*, and (v) *Market structure*.

It is worth citing Weber [27], who, in very concise viewpoint but with suggestions for further research, proposes a distinction of the barriers into: (i) *Institutional*, (ii) *Market* (barriers and failures); (iii) *Organizational*, and (vi) *Behavioral*.

2.1. The Sorrell et al. taxonomy

A crucial contribution to the classification of barriers to energy efficiency has come by Sorrell et al. [28], with further modification [10] and a more recent discussion [29]. The authors, taking important elements from Jaffe and Stavins [5] and Golove and Eto [30], propose a new categorization of barriers, built on the theoretical background of the barrier, i.e., economic, behavioral, organizational (see Table 1). This study is currently a key reference in the literature on barriers [31–35].

Starting from the economic perspective, a vast literature basis since the 1970s (for a collection of previous studies, see e.g., Krieg [36]) addressed the topic of energy efficiency, with the identification, according to neo-classical theories, of the so-called *market barriers* to the adoption of energy-efficient technologies. In the context of energy efficiency, market barriers refer to any market-related factor that inhibits energy efficiency improvements [24,37]. It is possible to summarize the market barriers to three main groups: when energy costs are not a major concern, when they are low relative to costs of many other goods and services, and thirdly, when the investment is inhibited by barriers in capital markets.

It is worth noticing that critiques on earlier attempts to categorize barriers [38,39] helped to more clearly distinguish *market failures* with respect to *market barriers*. In particular, according to the neo-classical theories, market failures occur when more requirements for an efficient attribution of the resources are violated [5,9,40]:

- A complete set of markets with well-defined property rights exist such that buyers and sellers can exchange assets freely;
- Consumers and producers behave competitively by maximizing benefits and minimizing costs;
- Market prices are known by all consumers and firms; and
- Transaction costs are zero.

Sorrell et al. [28] have adopted this perspective and clearly distinguished between non-market and market failures, as presented in Section 2.1.1. Moreover, Sorrell et al. have made the effort to include the two non-economic perspectives, i.e., the behavioral and the organizational, which will be addressed, respectively in Sections 2.1.2 and 2.1.3.

2.1.1. The economic perspective

2.1.1.1. The non-market failure barriers. Heterogeneity: although a technology may be cost-effective on average for a class of users, the class itself consists of a distribution of consumers: some could economically purchase the technology, while others will find the new level of efficiency not cost-effective [5,30,41].

Hidden costs: according to Nichols [42], engineering–economic studies fail to account for either the reduction in benefits associated with energy-efficient technologies or the additional costs associated with them. Therefore, studies overestimate efficiency potential. Nichols identified three broad categories of hidden costs: (i) general *overhead* costs of energy management, (ii) costs *specific* to a technology investment, and (iii) *loss of benefits* associated with an efficient technology.

Access to capital: many consumers have access to capital only at costs well above the average rate of return on capital in the economy. Hirst and Brown [43] identified and highlighted the difficulty to obtain capital, and several conclusions are confirmed in a recent study by the United Nations Environment Programme (UNEP) [44]. Further evidence of the Access to Capital barrier can be found in recent studies [32,45–52]. This might be particularly critical for low income households but also for SMEs, as noticed by several authors [19,53–56]. Golove and Eto [30] have argued that this barrier can be better understood as an information problem due to a cost entailed in investigating the credit worthiness of small firms and individuals.

Risk: according to Sorrell et al., both high discount rates for energy efficiency and the rejection of particular energy efficient technologies may represent a rational response to risk. The study distinguishes three broad categories, as follows: (i) *External* Risk, (ii) *Business* Risk, and (iii) *Technical* Risk. The authors point out that “risk may be difficult to evaluate objectively and while *perceptions* of risk may inhibit investment, this does not mean that those perceptions are rational”. As example, the uncertainty about energy prices, especially in the short term, seems to be an important barrier, as stressed by Velthuijsen [57] that often leads to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate [24], thus inhibiting an investment.

2.1.1.2. The market failure. Imperfect information: the insufficient information about the energy performance of different technologies lead consumers to make sub-optimal decisions based on provisional and uncertain information, and consequently to under invest in energy efficiency [5,37]. Moreover, as Hewett and IPCC note [58,24], the problem is likely to be more serious in some cases: first, the product or service is purchased infrequently – such as large investments in new and more energy efficient technologies – second, the rate of technology change is rapid relative to the interval between purchases; and, third, it is often difficult to

Table 1
Different perspectives of energy efficiency barriers according to Sorrell et al. [19].

Perspective	Examples	Actors	Theories
Economic	Imperfect information, asymmetric information, hidden costs, risks.	Individuals and organizations considered as rational and aiming at maximizing profits.	Neo-classic economy
Behavioral	Incapability to process information, form of information, inertia.	Individuals with bounded rationality, with non-economic behavior and/or under various social influences.	Transaction costs economy, psychology, decisional theories.
Organizational	Lack of power and/or influence by people in charge of energy management; lack of organizational culture leads to ignore energy issues	Organizations are considered as social systems influenced by objectives, routines and structures with different power.	Organizational theories.

quantify the energy savings that resulted from its installation, since usage patterns may have changed.

When parties to a transaction have access to different levels of information, they create the so-called *asymmetric information* barrier, i.e., a special form of imperfect information, leading to the three following barriers: split incentives, adverse selection and principal–agent relationships.

Split incentives: this barrier, also called *misplaced incentives* [9], is related to the appropriation of the benefits, and has been recognized for many years as being of major importance [23]. For example, individual departments in an organization may not be accountable for their energy use, thus lacking incentive to improve efficiency. Or, as DeCanio [59] notes, quite often managers remain in their post for relatively short periods of time, thus having no incentive to initiate investments with a longer payback period.

Adverse selection: as Hewett [58] notes, *credence goods*, i.e., goods for which the consumers have large difficulties to ascertain the quality and the effectiveness prior to purchase, such as energy-efficient technologies or services, are particularly vulnerable to adverse selection [8]. Hence, in the industrial world, purchasers might tend to buy technologies according to visible aspects such as price, and be reluctant to pay the price premium for high-efficiency products.

Principal–agent relationships: this barrier might be found in the energy service market and within organizations. To ensure interests are met, the principal may strictly monitor the agent, and/or create an appropriate incentive structure. For example, DeCanio [60] observed that firms use very stringent payback criteria which are significantly greater than firm's cost of capital. For further evidence, see, e.g., [30,37,61–64].

One of the greatest benefits of the study performed by Sorrell et al. is the inclusion of other non-economics perspectives in the taxonomy, i.e., behavioral and organizational, according to "the wide range of empirical research that has demonstrated that assumptions of economic rationality on the part of energy users are fundamentally flawed" [28,65].

2.1.2. The behavioral perspective

2.1.2.1. Bounded rationality.

The authors note that, as a consequence of *bounded rationality* introduced by Simon [66], individuals and companies will tend to make satisfactory decisions rather than searching for optimum decisions. Moreover, constraints on time, attention, resources and the ability to process information, lead to optimization to be replaced by imprecise routines and rules of thumb.

With the expression of Bounded Rationality it sounds clearer that decisions are not taken as established by rational rules given by economics. Instead, decision-makers are bounded by many limitations in attention and resources, being able to elaborate only a limited set of information. This phenomenon has not been considered in the traditional economic models: nonetheless, it might be important for the energy service market, characterized by presenting complex and considerable information costs. For example, the attention is almost exclusively devoted to the core production activities, ignoring or neglecting activities considered as a peripheral issue, as energy management.

Sorrell et al. underline that, differently from what suggested by Eyre [67], they do not consider it as a market failure, rather a departure from the logic of economic rationality, as suggested by Sanstad and Howarth [62], and quote several empirical studies of energy decisions supporting the hypothesis of bounded rationality (see, e.g., de Almeida [68]), showing how e.g., payback rules and capital budgeting may represent different types of routines.

2.1.2.2. The human dimension.

Form of information: this barrier is considered crucial, since information, for not being ignored, should be specific, personalized, vivid, clear, simple, close in time to the relevant decision and before the investment in a new energy-efficient technology. In addition to that, and, as suggested by Seligman [69], "feedback should be given on the beneficial consequences of previous energy decisions if subsequent efficiency measures are to be encouraged".

Credibility and trust: Stern [70] notes that is important for a successful diffusion of energy-efficient technologies that the information source is credible. Although the existence of Form of Information, Credibility and Trust refer to distinct aspects of information, Sorrell et al. combine them, claiming they can be hardly distinguished in empirical research.

Inertia: based on the study by Hewett [58], this barrier represents the combined effect of treating gains differently from losses, giving greater weighting to certain outcomes with respect to those that are uncertain, and minimizing the regret. All three factors may cause individuals and organizations to favor the status quo. As an example, suppliers might deliver what they think consumers want, but in markets characterized by a high degree of Inertia or risk aversion by suppliers, there may be latent demand for higher levels of energy efficiency than readily available in the market [24].

Values: taking the inspiration outside industry [28], the lack of individuals motivated by environmental values may downgrade energy efficiency as a peripheral issue. Indeed, it is a behavioral barrier for which energy-efficient technologies may neither be adopted nor promoted. This barrier represents a concrete improvement in the research, pointing out clearly that economic considerations are just one of the elements for a decision. Therefore, values represent a relevant explanatory variable to explain the efficiency gap.

2.1.3. The organization theory perspective

If we look at enterprises as systems with relationships and conflicts among individuals and departments with different cultures influencing decision-making, it is important to note that the firm's organization might represent a barrier to the adoption of energy-efficient technologies.

Power: due to divergent interests within the firm, it seems clear that possible conflicts for the use of limited resources may arise. As expressed by Morgan [71], Power represents the medium through which conflicts of interest get resolved, influencing "who gets what, when and how". As the responsibility for energy issues is usually assigned to engineering or maintenance departments (and, in some cases for SMEs, the two may coincide), it is possible that top management considers energy issues as peripheral, thus limiting its power, funds and support. Therefore, energy efficiency opportunities, although technically and economically viable, may be missed.

Culture: according to Hatch [72], "culture is broadly defined as the mix of knowledge, ideology, values, norms, laws and day-to-day rituals that characterize a social group". Culture represents a relevant variable in explaining the failure to adopt energy-efficient technologies, as also recently pointed out by Palm [73].

3. The need for a new taxonomy

3.1. Issues arising from the literature review

3.1.1. Missing elements

Looking at the taxonomy of Sorrell et al., we observe that several barriers have not been included or explicitly addressed, i.e.,:

- By considering market barriers, we can observe the *distortion in energy resources prices* [43]. This is an important aspect for

energy efficiency, since the price that consumers pay does not fully reflect the external cost of energy. Most environmental and social costs associated with fuel production, consumption, transmission and use, are neglected;

- As addressed by Hirst and Brown [43], Jaffe and Stavins [5], and Brown [9], the *low diffusion of technologies* should be considered as a barrier, because it implies that technologies are not actually fully available, as well as the training and the expertise to manage them. Therefore, it represents a barrier that should be explicitly addressed;
- As emerged in an empirical study by Trianni and Cagno [19] we can appreciate the barrier *difficult access to external competences*. This barrier should be clearly distinguished from the hidden costs barrier, since it points out a market problem rooted outside the company;
- As proposed by Howarth and Andersson [7], high initial costs should be considered as a separate barrier, since they cannot be completely referred to hidden costs and capital availability barriers;
- The *distortion in fiscal and regulatory policy,* as modeled by Hirst and Brown [43] and Brown [9], should be considered a separate barrier. This has been empirically proven, e.g., by Alderfer et al. [74] for the installation of distributed generation, by Koomey [75] for commercial buildings, by Nagesha and Balachandra for small-industry clusters [76] and by Kranz and Worrell for CHP [77];
- The *perception of being already efficient* represents an important behavioral barrier, as shown by Vine et al. [78] in a research for promoting energy-efficient technologies and practices in California;
- The l*ow priority of energy issues,* as underlined by DeCanio [59], should be explicitly addressed within organizational barriers. Indeed, as expressed by Hirst and Brown [43], several factors cause energy issues to be put on the bottom of firm's priorities, discouraging investments in energy conservation. This includes a possible fall in energy prices, as it happened in the 1980s [38]. Furthermore, as summarized by Brown [9] and, with further empirical evidence, by a recent study of the International Energy Agency [37], when energy costs are a small portion on total production costs, it is easier for enterprises to ignore them;
- *Technology-related* barriers can represent, in some cases, a really important issue for the deployment of energy-efficient technologies. As empirically shown by de Almeida et al. [26], the "technical characteristics may not be applicable" may itself represent a factor hindering energy efficiency;
- Other studies – as highlighted by Shipley and Elliott [79] – have identified barriers such as the *lack of expertise and competences to identify the inefficiencies and opportunities and to implement energy efficiency measures*, as empirically pointed out within SMEs in two recent studies by Thollander et al. [80] and Trianni and Cagno [19].

3.1.2. Overlaps

Disaggregating the barriers according to the theoretical models enables to collect and investigate different approaches (e.g., economical, behavioral, and organizational), and provides different perspectives of analysis. Nonetheless, this approach may result in a partial overlap of barriers, since the proposed barriers often represent elements in which implicit interactions exist. For example, transaction cost economics combines neo-classical ideas with behavioral theories (e.g., bounded rationality) and derives an explanatory theory for the existence and structure of organizations [81].

Heterogeneity: although the argument is straightforward – i.e., some users could economically purchase additional efficiency, while others will find the new level of efficiency not cost-effective – it could be the result of the combined effect of different barriers, that should be separated. As for technological risks, depending on the specific situation, for one factory may be greater than for another. The same can be observed for Hidden Costs, that might be quite specific for a firm. Moreover, different parameters to evaluate the economic performance of an intervention could lead to contrasting conclusions. Additionally, when Principal–Agent Relationships occur, higher hurdle rates can be established, thus reducing the economic efficiency of several considered measures. For these reasons, Heterogeneity of the technology is recognized as a barrier to energy efficiency, but it does include many different issues that should be investigated separately.

Imperfect information: Sorrell et al. define this as a barrier, but, as suggested by several authors [9,24,43,62], it could be more appropriate to see this market failure as a set of barriers, comprehensive of all the problems related to the information flow. Therefore, on the one hand, we can see overlaps with Hidden Costs, by means of the transaction costs for gathering, analyzing and applying the interventions [30]. On the other hand, imperfect information encompasses the market failure asymmetric information, leading to Adverse Selection, Moral Hazard and Split Incentives.

Incomplete markets for energy efficiency: as clearly expressed by Blumstein et al. [23], "even though a conservation measure or device is cost-effective, it may not be on the market". Despite the fact that the diffusion of economically superior technologies is typically gradual [5], it is possible that, as suggested by Golove and Eto [30], certain powerful firms may be able to inhibit the introduction by competitors of energy-efficient, cost-effective products.

Bounded rationality: Adverse selection may be the result of bounded rationality in a context in which the decision-maker does not know the benefits of the opportunities. As an example, in case of Adverse Selection, a lack of information will lead to a decision based on the most evident characteristics. Nonetheless, bounded rationality leading to adopting imperfect evaluation criteria might be used also in Principal–Agent Relationship dynamics, where the criteria of judging the investments are affected by approximations (e.g., due to lack of time or competences). In this case, the behavioral Bounded Rationality barrier according to Sorrell et al. clearly overlaps with the Power organizational barrier.

3.1.3. Implicit interactions

Sorrell et al. admit to possible interactions between the barriers. These are the possible relationships (e.g., causal, combined effect, etc.) between one barrier – or a set of barriers – with another barrier – or another set of barriers – i.e., the former could modify the latter in different ways. Therefore, several problems arise when identifying and developing policies and measures to address those barriers. We would prefer to call them "implicit interactions", because the definition of barriers themselves implies those interactions. Differently from the overlap, in which two barriers partially look at the same problem, in this case the barriers are distinct, but an intrinsic link between them exists.

Looking at the taxonomy by Sorrell et al., some implicit interactions can be highlighted:

- Lack of Time, attention and competences to understand the information represent barriers strictly related to the adoption of approximate criteria to evaluate energy efficiency investments, are combined by Sorrell et al. in the Bounded-Rationality barrier;
- Principal–Agent Relationships represent the dynamic of two separate barriers, i.e., the lack of instruments to control

operators and an opportunistic agent-behavior. The simultaneous combined action might result in higher rates of return;

- Access to Capital represents the barrier that looks at the firm's economic and financial availability – in terms of both borrowed capital and internal funds – ,with respect to the capital devoted for investments in energy efficiency opportunities. This barrier is modified by the concurrent effect of two separate barriers: on the one hand, the investment priorities (behavioral barrier, e.g., decision-makers sensibility to energy efficiency); on the other hand, the effective total capital availability (economic barrier).

4. A novel taxonomy for energy efficiency

4.1. Designing a new taxonomy

The literature review demonstrated that several issues still need to be addressed. First, a taxonomy for energy efficiency that encompasses all the previous contributions needs to be developed. In particular, to clearly identify the barriers, it is important to precisely separate all the barriers, thus avoiding any possible overlap or implicit interaction. Therefore, on the one side, the elements of the taxonomy should be reduced to the minimum terms, in order to analyze the possible interactions among independent barriers. On the other side, this implies to perform the classification of the barriers according to the actors affected by the barriers for the energy-efficient purchases and operational decisions. In this regard, the latter proved to be quite effective, e.g., as for the identification of the barriers to the implementation of cleaner production practices [82].

Moreover, in order to be a really useful tool for enterprises and policy-makers, the taxonomy needs to be developed and shaped to be applicable to empirical research. Without a clear distinction between perceived and real barriers, a policy for industrial energy efficiency may result to be ineffective or inefficient.

4.2. Description of the barriers

The taxonomy has been developed to include the relevant barriers observed in the literature, separating and assigning them to the actors involved.

For what concerns the actors involved in the energy-related purchases and operational decisions (and thus on barriers acting on them), we have followed the approach proposed by Hirst and Brown [43] (see Fig. 1). Indeed, an enterprise operates within a given market that includes other actors (i.e., designers/manufacturers, technology suppliers, energy suppliers, capital suppliers). Barriers inhibiting the shift from the *status quo* to the *status of energy efficiency improved* arise within this market, and not just within the single enterprise. Nonetheless, the enterprise and the actors within the market are subject to regulation. As for example, regulation and policy may affect the diffusion of technologies and/or energy suppliers imposing standards or particular policies to regulate the market, modifying the price and/or the availability of services/products, as well as influencing a single firm through various policies.

The barriers have been reduced to lowest independent denominator, reaching a high level of detail, presenting elements that might occur autonomously. This prevents from overlapping or implicit interactions, as found in the literature. Therefore, slightly modifying definition given by Sorrell et al., we define a barrier as "a postulated mechanism that inhibits investment in technologies that are both energy efficient and (apparently) economically efficient", *without the necessity that one or more other barriers occur*.

Below we try to provide a preliminary description of the barriers extending the analysis to the actor affected by the barriers. With respect to the taxonomy developed by Sorrell et al. [28], we are considering more authors, thus going beyond a single enterprise (Table 2), and, with regard to this, of course, several repetitions of the barriers might occur. Nonetheless, in the empirical investigation, this would likely simplify the identification of the responsibilities and the barriers.

4.2.1. The external (with respect to the firm) barriers

4.2.1.1. Market. Energy prices distortion: as proposed by Hirst and Brown [43], energy prices do not account for externalities. Indeed, as an example, the energy price may account for the different generation costs of energy during the day. As a consequence, energy efficiency would not be encouraged.

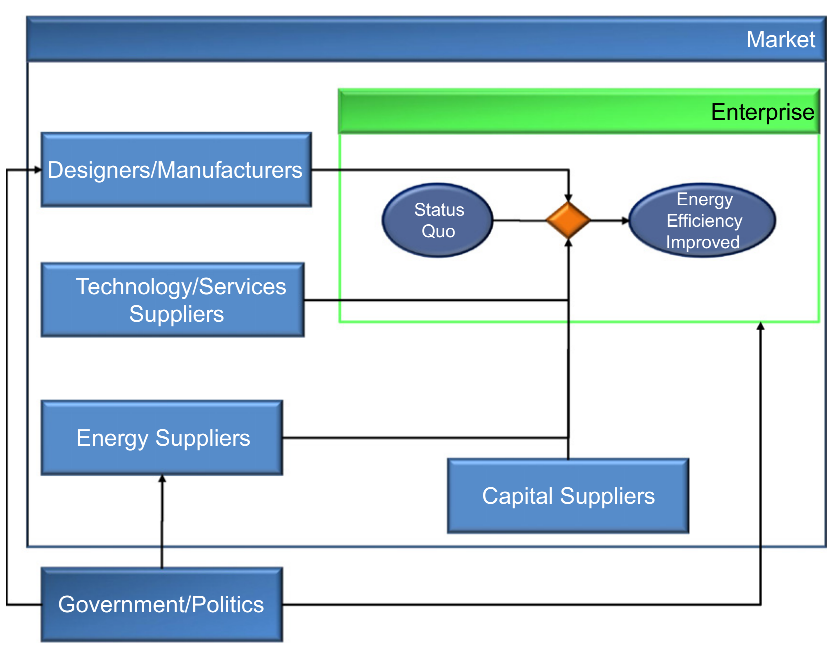


Fig. 1. Actors affected by the barriers for the energy-efficient purchase and operation decisions.

Table 2
The new taxonomy, with a clear distinction of the origin (external, or internal, with respect to the firm), and the actors affected by the barriers.

Origin	Actor/Area	Barriers
External	Market	Energy prices distortion
		Low diffusion of technologies
		Low diffusion of information
		Market risks
		Difficulty in Gathering External Skills
	Government/politics	Lack of proper regulation
		Distortion in fiscal policies
	Technology/services suppliers	Lack of interest in energy efficiency
		Technology Suppliers not updated
		Scarce communication skills
	Designers and manufacturers	Technical Characteristics not adequate
		High initial costs
	Energy suppliers	Scarce communication skills
		Distortion in energy policies
		Lack of interest in energy efficiency
	Capital suppliers	Cost for investing capital availability
		Difficulty in identifying the quality of the investments
Internal	Economic	Low capital availability
		Hidden costs
		Intervention-related risks
	Behavioral	Lack of interest in energy-efficiency interventions
		Other priorities
		Inertia
		Imperfect evaluation criteria
		Lack of sharing the objectives
	Organisational	Low status of energy efficiency
		Divergent interests
		Complex decision chain
		Lack of time
		Lack of internal control
	Barriers related to competences	Identifying the inefficiencies
		Implementing the interventions
	Awareness	Lack of awareness or Ignorance

Low diffusion of technologies: following Jaffe and Stavins [5], and Golove and Eto [30], the high energy-efficiency technologies quite often suffer from low diffusion, due to their innovative character. Indeed, "the adoption of new technology is typically gradual" [5].

Low diffusion of information: this barrier refers to the time needed to refine and disseminate information on energy-efficient technologies, as defined by Jaffe and Stavins [83].

Market risks: as suggested by Hirst and Brown [43], uncertainties regarding future energy prices might represent a barrier to investments.

Difficulty in gathering external skills: the prices and/or availability of experts might represent a barrier in the supply of existing energy-efficient technologies, as empirically observed by Trianni and Cagno [19].

4.2.1.2. Government/politics. Lack of proper regulation: as proposed by Wiel and McMahon [84], the lack of standards or classes (e.g., through clear labeling) for energy performance might represent a barrier to select the most effective energy-efficient technologies.

Distortion in fiscal policies: this barrier includes all the issues related to distorted fiscal policies, as suggested by Hirst and Brown [43]. Indeed, as proposed by the IPCC [24], the distortion in fiscal policies might consist in taxes, subsidies, or other policy interventions that "make resource consumption more or less expensive to consumers", discouraging the adoption of resource-conserving technologies.

4.2.1.3. Technology/services suppliers. Lack of interest in energy efficiency: Reddy [85] has shown that technology suppliers may get higher returns in commercializing lower energy efficiency technologies, thus being reluctant to deliver high energy-efficient solutions.

Technology/services suppliers not up to date: as Hirst and Brown suggest [73], if "companies that manufacture, distribute and service energy-efficient products provide only limited training to keep their employees abreast of the latest technologies", their customers will not be sufficiently and adequately informed, thus possibly selecting inefficient or even obsolete technologies.

Scarce communication skills: as shown by Hirst and Brown [43], energy-efficient technologies might be ignored if suppliers are not able to communicate their effective performance.

4.2.1.4. Designers and manufacturers. Technical characteristics not adequate: as suggested by de Almeida et al. [48], the *technical characteristics* of energy-efficient technologies might be very particular, resulting hardly to be adopted in some cases, irrespectively of their costs. This differs clearly from the definition of Heterogeneity provided by Sorrell et al. [28], which is based on cost-effectiveness.

High initial costs: as proposed by Howarth and Andersson [7] and Reddy and Shrestha [86], high initial costs to adopt new energy-efficient technologies represent an important barrier, possibly reflecting the high design and manufacturing costs to deliver an up-to-date energy-efficient technology. We can assume that this barrier, although perceived by a firm when purchasing a technology, is also a barrier in design and manufacturing.

4.2.1.5. Energy suppliers. Scarce communication skills: as reported by Sorrell et al. [28] different options in energy contracts can be presented in a form that might be unclear and not-vivid, thus resulting to be unattractive for the customers.

Energy prices distortion: the energy prices do not fully reflect the costs borne by producers in the different hours of a day, as suggested by Hirst and Brown [43] and Brown [9]; moreover, the energy prices might not provide sufficient incentive to adopt energy-efficient technologies, since, as supported by a vast empirical experience, the higher the use, the lower the energy rate.

Lack of interest in energy efficiency: as proposed by Reddy and Shrestha [86], the firm's energy costs reduction implies lower returns for energy suppliers. Thus the latter might be not interested to have their clients informed about energy-efficient solutions.

4.2.1.6. Capital suppliers. Costs to investigate debt carrying capability: as shown by Berry [87] and Schleich [88], and extensively analyzed by IPCC [24], the high transaction costs to evaluate debt carrying capability and to service a large number of small and medium-sized projects – typical for energy-efficient technologies – might be considerable, thus discouraging investors to finance energy efficiency investments.

Difficulty to identify the quality of investments: as suggested by IPCC [24], capital suppliers might incur difficulties in evaluating the investments for which they provide capital; thus, they might tend to grant capital only to well-known solutions, preventing innovative energy-efficient technologies to be diffused.

4.2.2. The internal (within the firm) barriers

Several barriers are originated within the firm. Every function within the enterprise (see Fig. 2) is characterized by its competences and behavior concerning energy. The simpler the organization within the enterprise, more functions will be represented by a single decision-maker.

When considering the internal barriers, we decided to follow the approach provided by Sorrell et al., thus analyzing the barriers

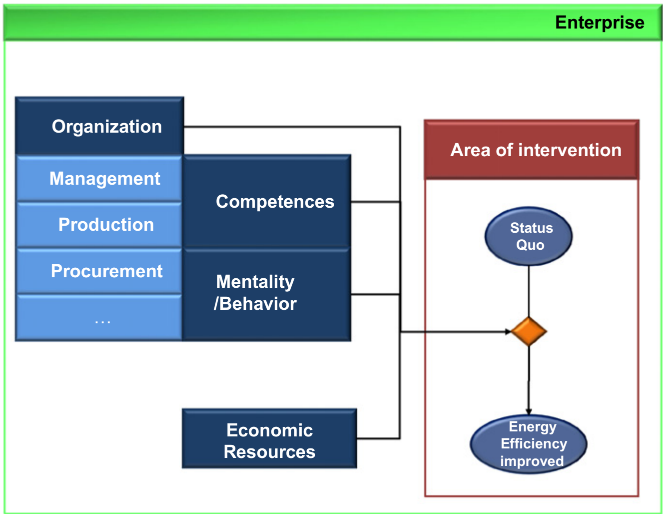


Fig. 2. The functions, within the firm, involved in the energy-efficiency decision-making process.

by category. This is of fundamental importance for the taxonomy, since, if the internal barriers were analyzed as the external ones, i.e., according to the involved actors – as done in Section 4.2.1 – two major problems would appear. Firstly, when performing an empirical investigation, each behavioral barrier would be repeated for each function within the enterprise, thus increasing the number of barriers at the lowest level of the taxonomy. Secondly, considering the unique mix of functions and features that characterizes the single enterprise in terms of specific organizational structures, it hardly seems feasible to develop such a flexible taxonomy.

4.2.2.1. Economic barriers. In this section we present the barriers related to the economic evaluation of an energy efficiency investment.

Low capital availability: as demonstrated by several empirical studies [19,32–33,45], even with a great awareness on the benefits of energy-efficient technologies, and considerable commitment of management and personnel to energy, the firm does not have sufficient own capital to invest in energy-efficient technologies.

Hidden costs: those costs might differ significantly from the estimate in investment analyses: as proposed by Ostertag [89], all the transaction costs to obtain information on energy-efficient technologies and related personnel training fall within this category. A further classification within this category can be provided: e.g., Hidden Costs can be distinguished according to the project stage in which they occur.

Pre-intervention Hidden Costs include the research of energy inefficiencies and opportunities to increase energy efficiency [88]. In addition to the expenditures for energy audits, as underlined by Jaffe and Stavins [5], the costs to perform a preliminary evaluation of the investment and the costs to understand the debt carrying capability should be considered.

Focusing on the costs *during* the implementation of the investment, the introduction of new technologies may require the interruption, at least partially, of normal operations, thus incurring into disruption costs, as shown by Sorrell et al. [28], that, although "quite often neglected in the evaluation of the investments, are real. In this sense, investors may take a rational decision not to invest in the light of this additional cost". We should not forget the costs related to all the modifications (e.g., layout of the equipment) needed to install the new energy-efficient technology.

Considering the *post-intervention* Hidden Costs, as empirically studied by Rohdin and Thollander [32], it is possible that the costs to train personnel, to develop new procedures for maintenance, to adapt to the modified production system may represent a barrier to invest in energy-efficient technologies.

Intervention-related risks: as suggested by Jaffe and Stavins [5], some uncertainties and risks occur when implementing the energy efficiency interventions. As shown by Ross [54] and Sanstad et al.[90], the discount rates for future costs and benefits exceed consistently the conventional rule of thumb rates chosen for investments, i.e., either the rate of return available on investments with comparable risk or the rate at which the purchase is financed.

Interventions not sufficiently profitable: as demonstrated by empirical evidence, some enterprises often rationally discard investments with a rate of return lower than their internal rate of return. This can be particularly critical especially for energy-efficient technologies requiring a significant change.

4.2.2.2. Behavioral barriers. In this section we present the barriers related to the behavior of operators and decision-makers within the firm.

Lack of interest in energy efficiency: this barrier includes several elements, each of those contributing to the perception that energy issues are not sufficiently interesting:

- Energy costs do not have sufficient weight with respect to the firm's production costs [9];
- The firm perceives itself as already efficient [91].

Other priorities: this is a barrier particularly critical for SMEs, where decision-makers might be focused almost uniquely on few core business activities. Therefore, they tend to exclusively evaluate the interventions with considerable impact on the main production system activities, thus disregarding energy efficiency, as emerged in empirical research (see., e.g., [32,33,19]).

Inertia: as Sorrell at al. pointed out, this barrier represents the resistance to change and risk, and the more radical the change, the higher the barrier will be. It can result in preferring interventions with quick and low investments and returns, thus slightly modifying the production system.

Imperfect evaluation criteria: the decision-makers might lack the proper knowledge or criteria to evaluate investments. In particular the decision-maker might adopt approximate criteria or routines, as suggested by DeCanio [59,92], that do not allow him/her to thoroughly evaluate the effective performance of the interventions. In other cases the decision-maker might adopt criteria for the evaluation (as pay-back period, or rate of return of the investment) without any relationship with the uncertainty associated to the considered alternatives.

Lack of sharing the objectives: as reported by DeCanio [59], some misalignments between the behavior of personnel and energy management objectives might occur, resulting in a low implementation of energy management practices [93].

4.2.2.3. Organizational barriers. The organizational barriers arise from the interaction of different functions within an enterprise in improving energy efficiency.

Low status of energy efficiency: as shown by Sorrell at al. [28], the functions devoted to energy management do not have sufficient power to act effectively to improve energy efficiency.

Split incentives: as suggested by Jaffe and Stavins [5] and reported by several others, the decision-maker might not gain the benefits from improving energy efficiency.

Complex decision Chain: as proposed by Sorrell et al. [28], and also considered in the study of Benhaddadi and Olivier[50], if the decision-making process involves several functions, the information flow might not be straight and smooth.

Lack of time: as reported by Nagesha [94], the decision-maker does not have enough time to consider energy efficiency opportunities.

Lack of internal control: without adequate control systems established by the management, the personnel within firms might not implement energy efficiency practices. This phenomenon has been investigated in the study by Sorrell et al.[28], thus leading to the principal–agent relationships and the consequent adoption of higher return rates for energy-efficient technologies.

4.2.2.4. Barriers related to competences. In order to implement energy efficiency interventions, specific competences have to be available within the organization. Indeed, those barriers can be particularly critical for SMEs, in which personnel might be trained to operate equipment but without sufficient knowledge to analyze inefficiencies, opportunities, and to implement the needed actions, as empirically emerged in recent research [19].

Identifying the inefficiencies: this barrier might occur when, even with a great awareness of the energy issues, and consciousness of the benefits of energy-efficient technologies, specific competences on methods and tools to identify energy waste are lacking.

Identifying the opportunities: similarly for the barrier Identifying the Inefficiencies, this barrier represents the difficulty to identify the opportunities to improve energy efficiency.

Implementing the interventions: this barrier shows the difficulty to implement practices and interventions for energy efficiency, without the support of external consultants or personnel.

4.2.2.5. Awareness. This barrier aims at pointing out the ignorance of decision makers on energy efficiency.

Lack of awareness (or *Ignorance*): as reported by de Almeida et al. [48], the Lack of Awareness represents a status – not a behavior (already reported as a behavioral barrier in Section 4.2.2.2) – of the decision-makers, in which they simply ignore the possible benefits coming from the implementation of energy efficiency opportunities.

4.3. A taxonomy for empirical investigation

As introduced in Section 4.1, one of the pillars of this study is to develop a taxonomy applicable to empirical research, which is fundamental to understand the real difficulties of the enterprises and develop the most effective policies to overcome the barriers. In order to adapt the novel taxonomy to the empirical investigation, we have slightly modified some internal barriers reported in Section 4.1.2 and have looked at the effect of the external barriers (reported in Section 4.1.1) on the firm, as reported in Table 3. In particular, we have decided to add two more categories, generally called Technology-related barriers and Information barriers.

4.3.1. Technology-related barriers

As described by Nagesha [94], considering two separate barriers, i.e., the Low Diffusion of Technologies (described in Section 4.1.1.1) and the Lack of Interest by Technology Suppliers (described in Section 4.1.1.3) in promoting and disseminating energy-efficient technologies, we can see that the effect of these barriers on the firm is exactly the same. Indeed, the firm perceives the energy-efficient Technologies as not Available, as it cannot recognize whether the unavailability of a given technology is due to the Low Diffusion of Technologies or to Lack of Interest by Technology Suppliers.

4.3.2. Information barriers

This category has been created in order to gather all the external barriers related to the information flow on energy-efficient technologies.

In particular, for an empirical investigation, we can find:

Lack of information on costs and benefits: this barrier collects the effects of several external barriers. In particular: the Low Information Diffusion (see Section 4.1.1.1), the Lack of Proper Regulation, in terms of classes of energy-efficiency performance of the technologies (see Section 4.1.1.2), and the Technology Suppliers not Updated on the new energy-efficient solutions (see Section 4.1.1.3).

Unclear Information by Technology Suppliers: this barrier might depend on the Lack of Communication Skills by technology suppliers (expressed in Section 4.1.1.3). Moreover, the Lack of Proper Regulation, in terms of classes of performance for energy efficiency (described in Section 4.1.1.2) might inhibit a clear comprehension of the information.

Trustworthiness of the information source: as expressed in Section 4.1.1.3, this barrier might occur when technology suppliers have Scarce Communication Skills to promote energy-efficient technologies, or due to a Lack of Interest in providing clear and detailed information to their clients.

Information issues on energy contracts: as described in Section 4.1.1.5, this barrier refers on the Scarce Communication Skills by energy suppliers in communicating the information, and/or a Lack of Interest in providing clear and detailed information to their clients.

4.3.3. Modifications of the internal barriers

The structure of the taxonomy presents some slight modifications for internal barriers, as reported in Table 3:

1. The investment costs and the External Risks should be added to the economic barriers described in Section 4.1.2.1;
2. The Low Capital Availability (Section 4.1.2.1) encompasses all the barriers referable to capital suppliers (Section 4.1.1.6);
3. The Difficulty of Gathering External Competences (expressed in Section 4.1.1.1) has to be added to the competence-related barriers (Section 4.1.2.4).

Interestingly, the external barriers reflect on the economic, the information and technology-related barriers, thus representing the impact of the external context on the firm. This does happen neither for the organizational nor for the behavioral internal barriers, that could even be independent of the external context. Lack of Interest for Energy Efficiency represents the unique exception, since it reflects how attentive the firm is towards energy efficiency. Indeed, this barrier will be strongly affected by the external context, such as the Energy Prices Distortion (Section 4.1.1.1), the Lack Proper Regulation – in terms of minimum standards for energy efficiency – the Distortion of Fiscal Policies (Section 4.1.1.2), and a Distortion in Energy Policies (Section 4.1.1.5).

We have performed six preliminary exploratory studies to validate the new taxonomy. In particular we have considered industrial North-Italian manufacturing enterprises belonging to different sectors, number of employees, annual turnover, energy expenditures, and different experience with the energy efficiency topic (i.e., having conducted energy audit, that, according to

Table 3
The proposed taxonomy modified for empirical investigation. The black cells highlight that the barriers of the “external barriers” columns. will be investigated through the correspondent elements of the “barrier for empirical investigation” column. In italics we have reported the barriers that have been added to the taxonomy for empirical investigation.

		EXTERNAL BARRIERS																
		MARKET					GOVERNMENT/ POLITICS		TECHNOLOGY SUPPLIERS			DESIGNERS AND MANUFACTURER S		ENERGY SUPPLIERS			CAPITAL SUPPLIERS	
		ENERGY PRICES DISTORTION	LOW DIFFUSION OF TECHNOLOGIES	LOW DIFFUSION OF INFORMATION	MARKET RISKS	DIFFICULTY IN GATHERING EXTERNAL SKILLS	LACK OF PROPER REGULATION	DISTORTION IN FISCAL POLICIES	LACK OF INTEREST IN ENERGY EFFICIENCY	TECHNOLOGY SUPPLIERS NOT UPDATED	SCARCE COMMUNICATION SKILLS	TECHNICAL CHARACTERISTICS NOT ADEQUATE	HIGH INITIAL COSTS	SCARCE COMMUNICATION SKILLS	DISTORTION IN ENERGY POLICIES	LACK OF INTEREST IN ENERGY EFFICIENCY	COST FOR INVESTING CAPITAL AVAILABILITY	DIFFICULTY IN IDENTIFYING THE QUALITY OF THE INVESTMENTS
TECHNOLOGY-RELATED BARRIERS	TECHNOLOGIES NOT ADEQUATE											■						
	TECHNOLOGIES NOT AVAILABLE		■						■									
INFORMATION BARRIERS	LACK OF INFORMATION ON COSTS AND BENEFITS			■			■			■								
	UNCLEAR INFORMATION BY TECHNOLOGY SUPPLIERS						■				■							
	TRUSTWORTHINESS OF THE INFORMATION SOURCE								■		■							
	INFORMATION ISSUES ON ENERGY CONTRACTS													■		■		
ECONOMIC	*LOW CAPITAL AVAILABILITY*																■	■
	INVESTMENT COSTS												■					
	HIDDEN COSTS																	
	INTERVENTION-RELATED RISKS																	
	EXTERNAL RISKS				■													
	INTERVENTIONS NOT SUFFICIENYLY PROFITABLE																	
BEHAVIORAL	LACK OF INTEREST IN ENERGY-EFFICIENCY INTERVENTIONS	■					■	■							■			
	OTHER PRIORITIES																	
	INERTIA																	
	IMPERFECT EVALUATION CRITERIA																	
	LACK OF SHARING THE OBJECTIVES																	
ORGANISATIONAL	LOW STATUS OF ENERGY EFFICIENCY																	
	DIVERGENT INTERESTS																	
	COMPLEX DECISION CHAIN																	
	LACK OF TIME																	
	LACK OF INTERNAL CONTROL																	
BARRIERS RELATED TO COMPETENCES	IDENTIFYING THE INEFFICIENCIES																	
	IDENTIFYING THE OPPORTUNITIES																	
	IMPLEMENTING THE INTERVENTIONS																	
	DIFFICULTY IN GATHERING EXTERNAL COMPETENCES					■												
AWARENESS	LACK OF AWARENESS OR IGNORANCE																	

Table 4
Main characteristics of the enterprises used as exploratory cases to preliminary validate the new taxonomy.

Enterprise	Sector	Employees (no.)	Turnover (k€/y)	Energy expenditures/Turnover (%)	Have you adopted EE interventions in the recent past (3 years)? (Y/N)	Have you conducted energy audits in the recent past (3 years)? (Y/N)
1	Primary metals	47	6,987	1.2	Y	N
2	Textiles	92	16,740	9.3	Y	Y
3	Plastics	129	13,807	1.9	N	N
4	Primary metals	203	37,284	7.1	Y	N
5	Basic metals	36	16,013	5.0	N	N
6	Textiles	286	43,435	3.3	N	Y

Schleich et al. [95] seems to have a positive effect in lowering barriers, or having implemented interventions specifically for increasing energy efficiency), as reported in Table 4.

Indeed, during the exploratory investigation it has been possible to categorize the operational difficulties of the enterprises to one barrier, and never happened to have one operational difficulty without being able to refer it to a single barrier.

4.4. *The importance of the real and perceived values of barriers for energy efficiency*

It is apparent that every barrier is associated with the perception of the decision-maker and the value that he/she attributes to this perception.

For example, when the same energy-efficient technology to two different firms has been proposed, as done in the preliminary investigation in the Textiles enterprises, in one case the decision-maker decided to not invest in it since he/she perceived it as not fitting to the firm's characteristics, whilst in the other case he/she has decided to adopt it. Nonetheless, the same technology has been proposed, being sure that it would perfectly fit in both cases, therefore with the same real value of the barrier Technical Characteristics not Adequate. This result pointed out that the different behavior of the two decision-makers cannot depend on the real value barrier, rather on a different perception of that barrier.

The interpretation scheme (Fig. 3) provides a picture of the real and perceived values of a given barrier. In particular, they jointly contribute (the former indirectly, through the latter; the latter directly) in creating the effect of the barrier on the firm's decisions.

In Fig. 4 we report two examples of the effect of the barriers emerged in the exploratory cases. In one of the two Textiles enterprises visited, considering the barrier Technical Characteristics not Adequate, the perceived (value of the) barrier is higher than acceptable, so that, even if the real barrier is lower, the firm has not undertaken the investment. In another case (Plastics enterprise), for the Imperfect Evaluation Criteria, the combination of the perceived and real barrier is acceptable by the firm, thus undertaking the investment. From the examples it is apparent that in the first case, if for other (than energy efficiency) purposes the investment is undertaken, the enterprise will experience a lower (than expected) effort to improve its energy efficiency. Therefore, if the investment would not be undertaken, a relevant opportunity of savings would be missed. Conversely, in the second case, since the decision would be made on the perceived value of the barrier, the enterprise would experience a greater (than expected) effort to improve its energy efficiency. Hence, the enterprise needs further resources to overcome the real barriers, thus risking, in case of unavailability of additional resources, to waste the investment already undertaken.

Therefore, it is important to assess the perceived and real values of each barrier, in order to make a clear distinction between the real barriers and those perceived. In Table 5 we report the classification of the barriers according to the origin (internal/external). It is worth noting that some barriers consider problems that might arise within or outside the firm. As a consequence, they may have both an internal and an external origin. For example, in one of the Primary Metal manufacturing enterprises, the barrier Intervention not Sufficiently Profitable was related, on the one hand, to the price of the technology to be adopted (external), on the other hand to the rate of return of the investment (internal).

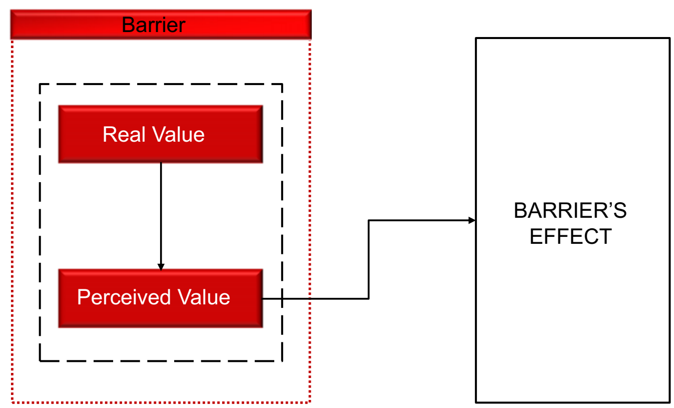


Fig. 3. The real and perceived values of a barrier and their indirect and direct effects.

4.5. *Effects of the barriers on the decision-making process*

The literature on energy efficiency decision-making is considerable and reviewing it would go beyond the scope of this article: nonetheless, we want to underline some studies devoted to models examining a firm's decision to implement a recommendation, thus analyzing which variables influence a firm's decision to adopt energy-efficient technologies (see, e.g., [96,97]). Tonn and Martin [98] have addressed, through a follow-up survey of 42 companies, the decision-making stages to adopt energy efficiency measures, identified as follows: (1) No energy saving decision-making, (2) Initial efforts, (3) Energy Efficiency Program Implementation, (4) Energy efficiency Program direct effect, (5) Routinization of Energy Efficiency Program, (6) internalization of Energy Efficiency Program, and (7) Steady State. This approach has been considered but modified in the conceptual framework recently developed by Hasanbeigi et al. [99]. In particular, they distinguish three important actions: (1) Awareness, (2) Motivation, and (3) Action. We adopt Hasanbeigi et al. framework for our analysis of the barriers on the decision-making process, showing how barriers might inhibit the shift from the first stage, i.e., status quo of energy efficiency, to the last one, i.e.. the energy-efficient technology implemented.

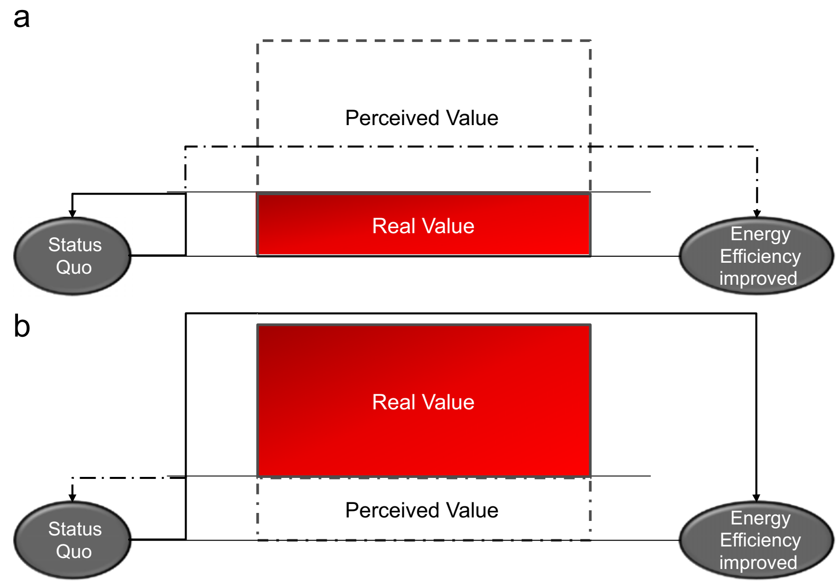


Fig. 4. Two possible results of how the combination of the real and perceived values of a barrier can affect the energy-efficiency improvement process.

Table 5
Table of synthesis of the taxonomy proposed for empirical investigation highlighting the characteristics of the barriers investigated. (a) The barrier may have its origin within the firm (Internal, I), or outside the firm (External, E); (b) The barrier affects the Action "Generation of Interest" (1), the Action "Research of inefficiencies and opportunities" (2), or the Action "Investment analysis and intervention implementation" (3). One barrier can affect multiple actions; (c) The barrier may affect any investment of the firm, i.e. not only those specific for the energy efficiency improvement; (d) The barrier, affecting exclusively energy efficiency, can be quantified in general (thus not depending on which action to be considered, G),or its value can vary according to a specific investment to be considered (intervention-dependent, D). One barrier can be both general and intervention-dependent.

Barriers for empirical investigation		(a) **Origin:** Internal (I) or External (E)	(b) **Decision-making step**	**Spectrum of influence of the barriers**	
				(c) To any investment	(d) To energy efficiency: general (D) or Intervention-dependent (D)
Technology-related barriers	Technologies not adequate	E	1, 3		D
	Technologies not available	E	1, 3		D
Information barriers	Lack of information on costs and benefits	E	2		D
	Information not clear by technology suppliers	E	2		D
	Trustworthiness of the information source	E	2		D
	Information issues on energy contracts	E	2		D
Economic	*Low capital availability*	I	1, 2, 3	1	G
	Investment costs	E	3		D
	Hidden costs	I/E	2, 3		D
	Intervention-related risks	I/E	3		D
	External risks	E	1		G
	Intervention not sufficiently profitable	I/E	3		D
Behavioural	Lack of interest in energy efficiency interventions	I	1		G
	Other priorities	I	1		G
	Inertia	I	1	1	G
	Imperfect evaluation criteria	I	3	1	G
	Lack of sharing the objectives	I	3		G
Organisational	Low status of energy efficiency	I	2, 3		G
	Divergent interests	I	1		G
	Complex decision chain	I	2, 3		G
	Lack of time	I	1, 3	1	G
	Lack of internal control	I	3		G
Barriers related to competences	Identifying the inefficiencies	I	1, 2		G/D
	Identifying the opportunities	I	1, 2		G/D
	Implementing the interventions	I	3		G/D
	Difficulty in gathering external competences	E	2		G/D
Awareness	Lack of awareness or ignorance	I	1		G/D

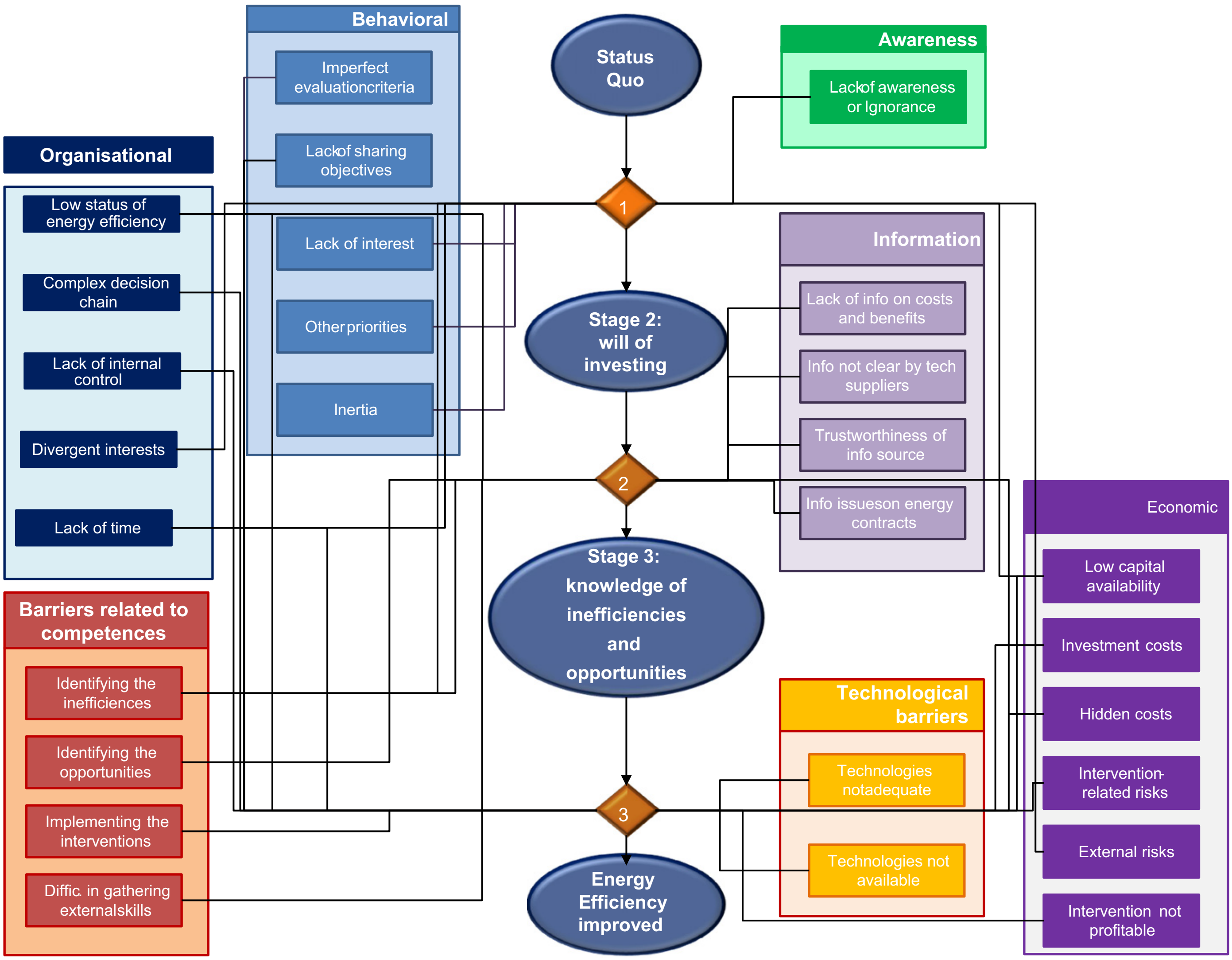


Fig. 5. The decision-making process and the barriers that can affect its actions, maybe inhibiting the change from one stage to another.

We report in Fig. 5 and Table 5 the proposed framework, also having taken benefits from the useful contributions provided by the preliminary investigation in the exploratory cases to refine the scheme. We acknowledge that this is a preliminary attempt to provide a framework which categorizes energy efficiency barriers based on the stage at which the barriers exist, and the research here is taking the first steps [100]. For clarity, since the interpretation scheme appears to be quite complex, we propose here to report the effect of a barrier only if it can independently inhibit the achievement of a stage, while we have not reported the effect of a barrier when acting in combination with other barriers. For example, the effect of Inertia is reported exclusively for the first stage. In fact, Inertia is supposed to hinder by itself the generation of the interest. We do not report the effect of Inertia in other stages. As example, in one Primary Metal enterprise of the preliminary investigation, Inertia was found to act concurrently with the Lack of Time, hindering the knowledge of inefficiencies and opportunities.

This preliminary scheme of identification of the barriers with respect to the decision-making process would provide a useful contribution in an empirical investigation, in order to clarify to both enterprises and policy makers the stages most affected by the barriers to energy efficiency.

Stage 1: Status quo. It is the energy efficiency status in which we can find the firm. It is rare that energy efficiency cannot be improved in any area.

Action 1: Generation of interest. This stage represents the generation of the awareness that energy expenditures can be reduced. This awareness arises the interest for energy efficiency, that represents the first step in the decision-making process.

Barriers here affecting the generation of interest towards energy efficiency: (1) Low Capital Availability; (2) Lack of Time; (3) Risks; (4) Divergent Interests; (5) Inertia; (6) Other Priorities; (7) Low priority of Energy Efficiency; (8) Difficulty in Identifying Inefficiencies.

Stage 2: Willingness to invest. The decision-maker is willing to invest resources in order to reduce his/her firm's energy consumption. We can reasonably assume that a firm stopping at this stage is aware of the importance of energy efficiency, but simply does not know how to do.

Action 2: Research of inefficiencies and opportunities. Once the firm is aware, the most critical areas with respect to energy efficiency need to be identified.

Barriers to the thorough knowledge of inefficiencies and opportunities: (1) Low Capital Availability; (2) Lack of Time; (3) Pre-intervention Costs; (4) Low Status of Energy Efficiency; (5) Complex Decision Chain; (6) Difficulty in Gathering External

Competences; (7) Lack of Competences in Identifying the Inefficiencies; (8) Lack of Competences in Identifying the opportunities; (9) Information barriers.

Stage 3: Knowledge of inefficiencies and opportunities. In this stage the decision-maker has the knowledge of the critical areas in which it would be necessary to act, as well as the actions needed. A firm that stops at this stage is aware of its gap for energy management and of several opportunities for improving its energy efficiency, but does not retain the interventions as applicable or convenient.

Action 3: Investment Analysis and intervention implementation. Once interventions, benefits and costs are known, the decision-maker has to evaluate whether the investment is adequate and if it this profitable, according to its own evaluation parameters.

Barriers to the implementation of the intervention: (1) Low Capital Availability; (2) Lack of Time; (3) Imperfect Evaluation Criteria; (4) Low Status of Energy Efficiency; (5) Complex Decision Chain; (6) Technologies not Adequate; (7) Technologies not Available; (8) Interventions not sufficiently profitable; (9) Lack of Control; (10) Lack of Sharing the Objectives; (11) Lack of Competences in Implementing the Interventions.

Stage 4: Intervention implemented, energy efficiency improved. If the investment analysis and the implementation of the intervention have been properly conducted, the firm will save on energy (costs). It is worth pointing out that the satisfaction for the success of the process is of fundamental importance for considering future interventions, and, thus, for the future firm's energy performance.

4.6. Spectrum of influence of the barriers

As the barriers have been categorized according to their origin and their influence with respect to the decision-making process, we need to shed the light on another important characteristic for the empirical investigation, particularly interesting for the analysis of the possible interactions, thus drawing to a wider picture of the barriers. The spectrum of influence of the barriers is indeed able to underline how general or specific the effect of the barrier is on the firm's decisions. Becoming more specific with respect to energy-efficient technologies, we can distinguish between three different levels (as reported in Table 5):

I. Barriers to investments: those barriers are not specifically related to energy efficiency, but generally consume the necessary resources for any investment and intervention;
II. Barriers to energy efficiency: those barriers represent a hurdle for any investment in energy-efficient technologies. Thus, they can be investigated regardless of the specific intervention to be considered;
III. Intervention-related barriers to energy efficiency: those barriers, whose values strictly depend on a specific energy-efficient technology, can be investigated exclusively considering a specific investment.

For example, by looking at the first level, the Low Capital Availability, Inertia, Imperfect Evaluation Criteria and Lack of Time do not necessary refer exclusively to energy efficiency, rather they can be considered as general barriers to investments. The barrier Difficulty in Identifying the Inefficiencies represents instead a general barrier for energy efficiency investments (second level), thus not depending on a specific intervention. It is now clear the difference with the third level: Hidden Costs can be investigated in their real values exclusively considering a specific investment in an energy-efficient technology, as emerged, e.g., in one of the Primary Metal manufacturing enterprises investigated.

4.7. Analysis of the interactions among barriers

The common simultaneous presence of several barriers in the same firm rises the attention in investigating the possible relationships among them, and trying to understand their possible impact. We identified, and preliminary tested through the six exploratory cases, three types of interactions: (1) causal relationship, (2) composite effect, and (3) hidden effect.

4.7.1. Causal relationship between barriers

The causal relationship between a barrier (A) and a barrier (B) exists when an increase of (B) is due to (A). This means that either (A) can generate (B), or just modify (B) (in case (B) already exists). The effect of the causal relationship might be delayed, i.e., the effect on (B) (creation or increase) might appear not simultaneously with (A). This implies that, as from the definition of barrier given in Section 4.2, once barrier (B) exists, it can stand autonomously even if barrier (A) decreases, or even disappears.

In Fig. 6 we show the causal relationship (continuous lines; real and perceived) between two barriers, (A) and (B). We also put in evidence (dotted line) how this generates an effect on the value of the perceived barrier (B) (that influences the decision-making process).

Taking into account the useful contributions emerged during the preliminary test performed in the exploratory cases, we report in Fig. 7 the scheme of causal relationships between the barriers. We acknowledge that they are not complete results, rather first insights that seems interesting to further explore with more detail in a wider empirical investigation.

We have expressed several links between behavioral and competences-related barriers: the presence of barriers such as Lack of Interest, Other Priorities and Inertia inhibits the development of the necessary competences for the identification of inefficiencies and opportunities, strengthening the ignorance on energy issues, as emerged in the Plastic enterprise. Moreover, Ignorance of the potential benefits would strengthen a Lack of Interest on energy issues, thus creating a vicious circle among Ignorance and Lack of Interest on energy efficiency. Additionally, Lack of Interest on energy efficiency might have a considerable influence on the Imperfect Evaluation Criteria. Indeed, adopting criteria unable to account for the equipment under a life-cycle costs perspective, can have an additional effect on the Inertia barrier. In fact, as highlighted in the Basic Metals enterprise, we observed a reluctance in changing the approximated and incorrect criteria adopted.

Fig. 7 depicts various relationships between behavioral and organizational barriers, since, e.g., a Lack of Interest can be found at all firm's levels, and may lead to Divergent Interests, since the firm cannot address correctly the benefits to the decision-makers responsible for the investment.

With respect to organizational barriers, the Lack of tools for internal Control on the energy efficiency decision-makers by the

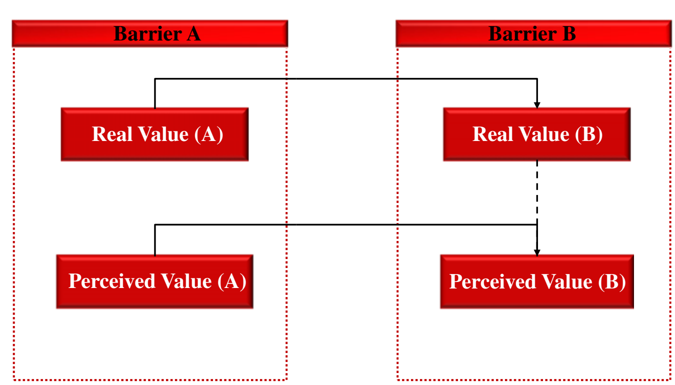


Fig. 6. The causal relationship between a barrier A and a barrier B.

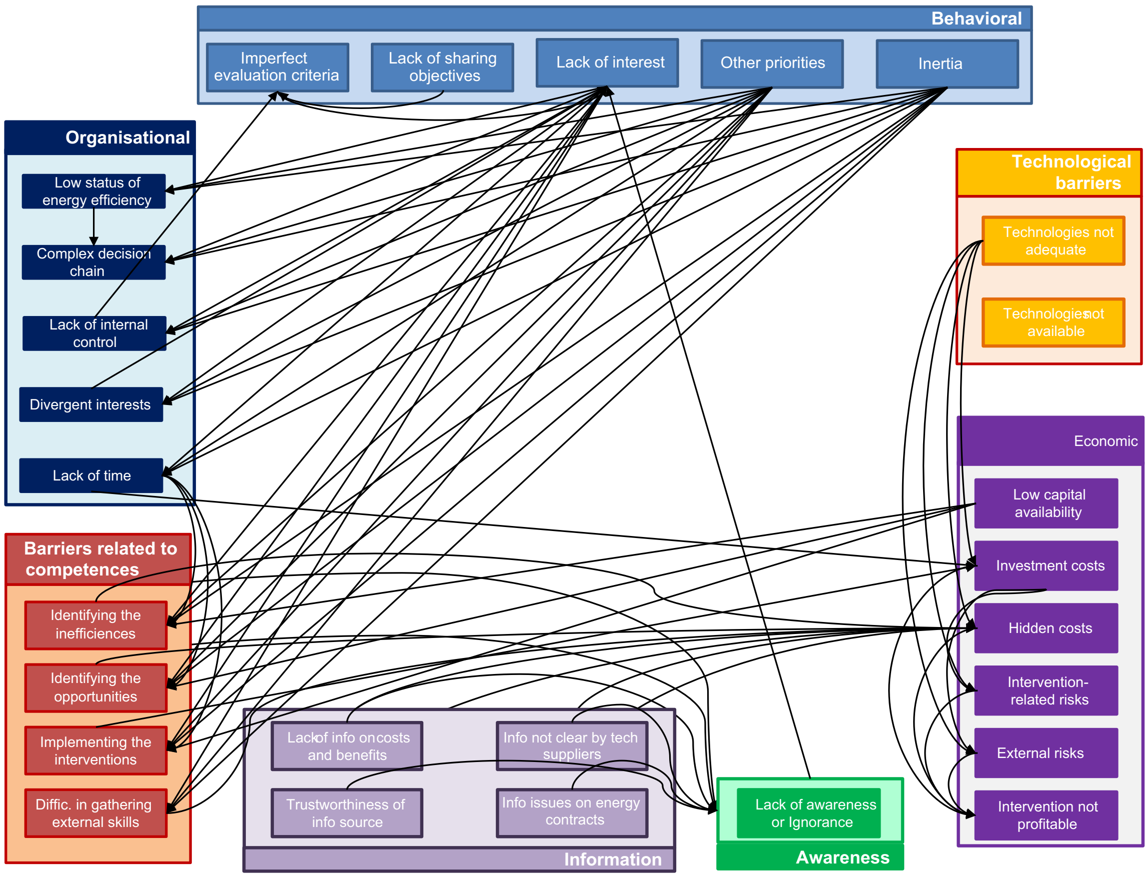


Fig. 7. Identification of the causal relationships between the barriers of the new taxonomy.

firm's management, and the possible Lack of Sharing the strategic firm's Objectives, might be the origin for adopting restrictive economic criteria on the energy-efficiency investments: this dynamic, known as Principal–Agent Relationship and Moral Hazard, has been widely investigated in the literature, as summarized by Sorrell et al. [10,28,29], and aforementioned. Moreover, as clear in the largest Textiles enterprise investigated, a Low Status of Energy Efficiency can originate the barrier Complex Decision Chain, making the decision-making process on energy efficiency investments long and complicated.

Furthermore, the Lack of Competences in Identifying both Inefficiencies and Opportunities may cause the Lack of Awareness on the real opportunities offered by the energy-efficiency market. Furthermore, it seems reasonable to assume that those lack of competences, due to a possible lack of resources (e.g., in terms of time and capital), might result in increasing the barrier Hidden Costs (usually before the investments) for evaluating the opportunities and investment costs, as empirically observed by previous research [19].

Finally, considering the economic barriers, we can see that High Investment Costs and Hidden Costs, as well as Intervention-related Risks, may act importantly in generating the Intervention not Profitable barrier, even if the energy efficiency performance of the intervention is proven to be, on average, positive [101]. Indeed, the characteristics of energy-efficient technologies might correspond just partially to the firm's needs, thus resulting in additional costs and unacceptable risks for the firm.

4.7.2. Composite effect

The composite effect of the barriers occurs when several barriers operate simultaneously: this means that, only if acting in combination with others, a barrier can inhibit the implementation of the intervention. As shown in Fig. 8, the composite effect between barriers (A), (B), and (C) exists when the value of another barrier (Z) is influenced by the existence of (A), (B), and (C). The continuous lines depict the composite effect between the barriers, (A), (B), and (C) on the value of (Z), while the dotted lines depict that the barrier (Z) affects both the perceived and real value of barrier (A), (B), and (C).

For example, we consider a case in which Hidden Costs, High Initial Costs and Resources for Higher Priorities Investments alone could not inhibit by themselves an investment. Nonetheless, as reported in Fig. 9, the composite effect of those barriers could make Low Capital Availability a barrier. Indeed, Hidden Costs, High Initial Costs and Resources for Higher Priorities Investments barriers influence the value of the Low Capital Availability barrier. Hence, it is also clear that the Low Capital Availability affects the perceived and real values of Hidden Costs and High Initial Costs barriers, as well as the resources for higher priority investments.

As expressed in Section 4.6.1, Hidden Costs might be caused by other barriers, that thus operate indirectly on the barrier Low Capital Availability. If collecting the information on the energy-efficient technology is difficult and additional resources are required, this will result in increased hidden costs.

Analogously, we can detect several barriers having a composite effect with the Lack of Time, particularly those reducing the time needed for taking a decision on the investment or enlarging the decision-making process, such as Information issues, Complex Decision Chain, Lack of Competences in Identifying both Inefficiencies and Opportunities, and Other Priorities.

As Inertia expresses the resistance to change and/or the resistance to perform large investment in the firm, it represents a barrier that tends to increase the several other barriers. As a

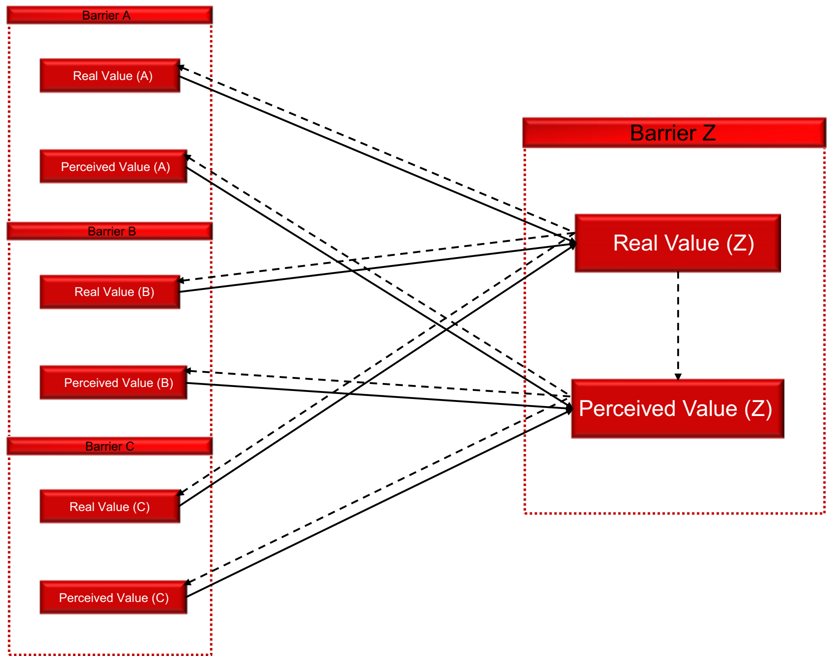


Fig. 8. The composite effect of three barriers (A), (B), and (C) on a barrier Z.

behavior against risk, Inertia appears each time the firm has to face a barrier that requires a strong initiative to be overcome. In this regard, Inertia has a composite effect with the Complex Decision Chain barrier and the economic barriers related to the energy efficiency investment, i.e., Investment and Hidden Costs, and Low Capital Availability, as highlighted also in the exploratory investigation.

We can see the composite effect of Inertia also at different decision making levels. Indeed, taking as example the larger enterprises tested in the preliminary investigation, although the reduction of energy consumption might represent a concern for the firm's management, achieving the energy savings still depends on the actions at lower levels. Indeed, we can note here that this is not a causal relationship, since the Lack of Control does not generate the Lack of Sharing Objectives. In fact, additional efforts in control do not have the effect of increasing the sharing of the objectives. Rather, there is large empirical evidence of lowered operators' willingness to adopt green practices through a tougher supervision. Moreover, this kind of interaction works in the opposite direction: indeed, it seems reasonable to assume that, in case of objectives widely shared, the Lack of Internal Control would probably be less important.

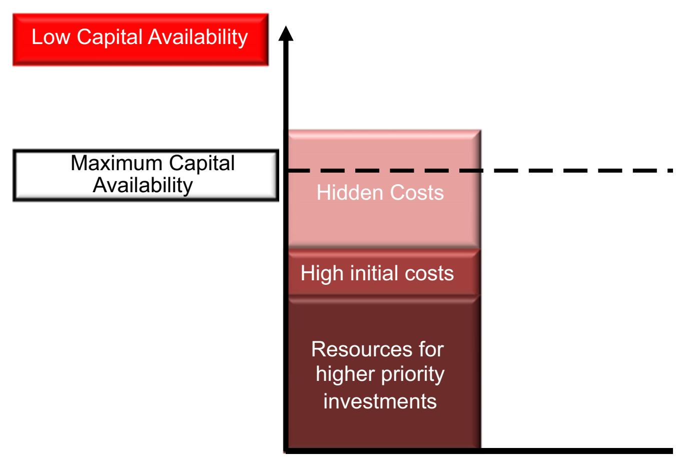


Fig. 9. The composite effect of three economic barriers on the low capital availability of the enterprise.

4.7.3. Hidden effect

The hidden effect of the barriers occurs when the firm is not aware of an existing barrier (A), whilst has the perception of being affected by another barrier (B): the presence of the barrier (A) influences the perception of barrier (B), therefore the firm will tend to confuse (A) with (B), as shown in Fig. 10. As a consequence, addressing (B) would be abruptly ineffective, since the real barrier is (A).

As emerged from the exploratory cases, the Basic Metal manufacturing enterprise incorrectly considered an energy-efficient technology as not adequate, due to a lack of knowledge on the most recent available technologies. In this case, the perception of the barrier Technology not Adequate represents a Lack of Competences in Identifying the Opportunities. Enterprises often acquire the knowledge of the opportunities proposed by the energy efficiency market through the research of information and the collaboration with external consultants. Therefore, a distorted perception of the real performance can be obtained, overestimating some barriers. Indeed, a technology can be considered as inadequate, or its costs and risks overestimated, due to unclear or untrustworthy information. This case clearly points out the hidden effect of Information issues and Lack of Interest for energy efficiency on the incorrect perception of the Lack of Competences for Identifying the Opportunities.

Analogously, we can note the hidden effect of several barriers behind the perception of the barrier Interventions not Sufficiently Profitable. As an example, quite often energy efficiency technologies are not considered as sufficiently profitable due to Imperfect Evaluation Criteria, or due to a Lack of Interest and Inertia that lead to inaccurate analyses to evaluate them, or due to an underestimation of their full spectrum of benefits.

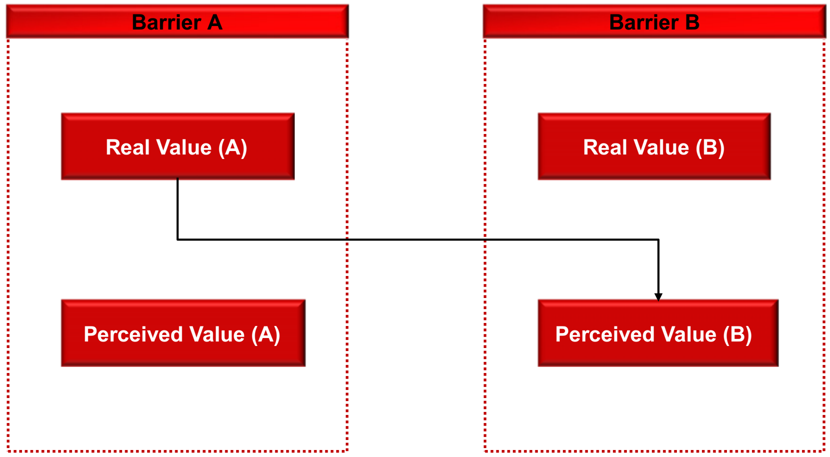


Fig. 10. The hidden effect of a barrier A on a barrier B.

5. Conclusions and further research

A deep understanding of the barriers to energy efficiency plays an important role both for enterprises and for future energy policies. Existing taxonomies on barriers do not include all the elements identified in the literature. Therefore, a novel approach has been proposed that aims to include all relevant contributions. The new taxonomy has been tested in a preliminary investigation of several enterprises – belonging to different industrial activities, and firm's size – where we have not found any other barrier not considered. Although the results seem to be sound, further research needs to be carried out, in particular analyzing more specifically the taxonomy by sectors, technologies adopted, and firm's size, since we think that the characteristics of the taxonomy could be shaped accordingly. This is the case of the firm's size, that seems to deeply impact on the organizational barriers.

The second issue is the presence of overlaps between barriers, causing an incorrect and misleading classification of the barriers. This is even more relevant when empirically investigating barriers within a specific firm. The new proposed taxonomy has tried to reduce the barriers to the minimum independent terms.

The third issue is the spectrum of influence of the barriers on the firm's decisions, i.e., how general or specific is its effect. We have proposed to distinguish between three different levels (barriers to investments; barriers to energy efficiency; and intervention-related barriers to energy efficiency). If the first two levels can be investigated at company level, the third one asks for a more specific analysis, encompassing intervention characteristics deployment (please refer to [15] for a valuable attempt). This analysis claims future attention on the relationship between intervention characteristics and barriers to energy efficiency.

The fourth issue is the existence of implicit interactions between the barriers, that, without being fully and thoroughly analyzed, would not allow a correct understanding of the mechanisms and dynamics behind the barriers. We have identified some existing relationships between them, i.e., causal relationship, composite effect and hidden effect. To do this, it was necessary to clearly distinguish between real and perceived values of the barriers. Indeed, the perceived value drives the investment decision-making process, while the real one is the barrier that the enterprise has to effectively overcome. We have preliminarily identified the primary effect of the barriers on the decision-making process steps. Moreover, we have tried to obtain an operative taxonomy, i.e., a taxonomy able to be empirically investigated. This has implied to distinguish between barriers originated outside or within the firm, and to understand the extent of the influence of a single barrier. The features of the new taxonomy have been tested through a preliminary investigation under a set of firms in Northern Italy. Nonetheless, future research is needed to further test the proposed taxonomy.

A last remark is needed on the driving forces that enable to overcome barriers to industrial energy efficiency. If several studies have investigated the barriers to energy efficiency, few have focused on the most effective means of promoting the adoption of energy-efficient technologies and practices. The literature is still limited to a small number of empirical contributions (see, e.g., [32,33,97,102]) and only recently some attempts for their classification have appeared [34,103,104]. Future research is needed to develop a taxonomy for drivers to energy efficiency, and thereafter to deploy the relationships existing between drivers and barriers.

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